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OPTIMIZATION OF FATIGUE LIFE OF PISTON THROUGH SHOT PEENING: PREDICTION & ANALYSIS

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ABSTRACT
The objective of this paper is to study the effect of shot peening on components made of Aluminum (Al2024) material. Shot peening is one of the process to optimize fatigue life of component. The FEA model was developed for assessing the effect of shot size, velocity, angle and distance on compressive stresses induced in the component. The compressive stress induced inside the component increase the fatigue life of material. The model was validated using physical experimentation. The residual stresses were measured using hole-drilling strain gauge method and fatigue life was estimated using 3-point bending test.

KEYWORDS: Shot-peening, Residual Stress, Design of Experiment, Finite Element Method ls dyne**,** Hole Drilling strain Gauge Method.

INTRODUCTION
Shot peening is a cold working operation process in which the surface of a part is bombarded with small spherical media called shot. Each piece of shot striking the material acts as a tiny peening strike conveying to the surface a small dimple. Appropriate dimple to be created, the surface stuff of the material must be produced in tension. Below the surface, the stuffs try to restore the surface to its original shape, thereby producing below the dimple and the hemisphere of cold worked material comes under highly stressed compression. Overlapping dimples develop an even layer of metal in left behind compressive stress. It is well known that cracks will not propagate in a compressively stressed area. Since nearly all fatigue and stress deterioration failures originate at the surface of a part, compressive stresses induced by shot peening provide considerable increases in part life. The maximum compressive left over stress produced by shot peening is at least as great as half the return strength of the material being peened. Various materials will also increase in surface hardness due to the cold operational influence of shot peening.

THEORY

2.1 SHOT PEENING:-
Shot Peening is a of cold working process in which compressive stresses are induced into the exposed surface layers of metallic parts and structures by impingement as shown in the fig. 1.The most common mechanical method used to treat the surfaces is shot peening, where spherical media is propelled by air or a centrifugal wheel and directed at a metal surface at high velocity and controlled parameters. Shot Peening is an operation which helps increase fatigue life and stress

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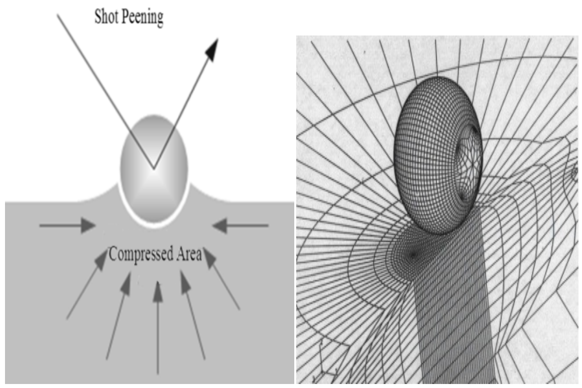
corrosion resistance by creating beneficial residual surface stresses that inhibits and/or delays crack initiation and propagation. The shot peening process has been a standard mitigating remedy in most cases for post machining, polishing and heat treating of high fatigue components. Common peening means are cast steel shot, conditioned cut wire, ceramic and glass beads, pistons and so on.



2.2 METHODS OF SHOT PEENING:-

I) CONVENTIONAL SHOT PEENING: Conventional shot peening is done by two methods. Method one involves accelerating shot material with compressed air. Shot is introduced into a high velocity air stream that accelerates the shot to speeds of up to 250 ft/s. The second method involves accelerating the shot with a wheel. The shot gets dropped onto the middle of the wheel and accelerates to the outer edge where it leaves on a tangential path.

ii) DUAL PEENING: Dual peening further enhances the fatigue performance from a single shot peen operation by re-peening the same surface a second time with smaller shot and lower intensity. Large shot leaves small peaks and valleys in the material surface even after 100% coverage has been achieved. Peening the surface a second time drives the peaks into the valleys, further increasing the compressive stress at the surfaces.

iii) AIR BLAST SYSTEM: In the case of fatigue analysis Air blast system or conventional method is utilized. In this method media is introduced by various methods into the path of high pressure air and accelerated through a nozzle directed at the part to be peened.

iv) CENTRIFUGAL BLAST WHEEL: The Centrifugal blast wheel consists of a high speed paddle wheel. Shot media is introduced in the centre of the spinning wheel and propelled by the centrifugal force by the spinning paddles towards the part by adjusting the media entrance location, effectively timed the release of the media.

2.3 RESIDUAL STRESS:

Residual stresses are stresses that remain after the original cause of the stresses (external forces, heat gradient) has been removed. Residual stresses occur for a variety of reasons, including inelastic (plastic) deformations, temperature gradients (during thermal cycle) or structural changes (phase transformation)**.** There are several techniques that are used to measure the residual stress. They can be classified as destructive and non-destructive methods. Mechanical methods or dissection uses the release of stress and its associated strain after doing a cut, hole or crack. Nonlinear elastic methods as ultrasonic or magnetic techniques require a reference sample.

2.4 METHODS OF RESIDUAL STRESS:

I) X-RAY DIFFRACTION: This method is a non-destructive method which allows the measurement of residual stress in isolated spots spaced distances as small as 100 micrometers.
ii)**NEUTRON DIFFRACTION**: This method is an alternative non-destructive method which allows measurement of residual stress in isolated spots. The choice between these two techniques depends on the design of the mechanical part to be tested.
iii) HOLE-DRILLING STRAIN-GAUGE METHOD: The hole-drilling strain-gauge method of measuring residual stresses in elastic materials can be termed semi destructive if holes of very small diameters are used. The method permits the magnitudes and principal directions of residual stresses at the hole location to be determined.
2.4 SHOT PEENING PREVENTS FATIGUE LIFE: By shot peening material, internal compressive stress areas are formed which oppose these tension stress regions and aid to prevent fractures in the material. The compressive stress areas in a shot peened surface are a residual effect and can profoundly increase the Fatigue life of the material.

SOFTWARE ANALYSIS OF VARIOUS PARAMETERS

The material selected for target is aluminum & that for shot is steel. The target material is circular in shape having its radius is 4mm & height is 8 mm. The Poisson ratio is 0.35. The density of the material is 2070kg/m^3.The material selected for shot is steel. The density of material is 7200 kg/m^3.The size of shot material is 1mm. In case of conventional peen forming, the component is kept straight during shot peening, while in stress peen forming, the component is elastically pre-bent before shot peening and kept bending during shot peening. With this 3D random model, LS-DYNA Explicit sequence solution is used to study the influence of pre-bending on the peen forming results. An explicit simulation with shots impacting at the pre-stressed component allowed determination of the average combined stress σ_{com} in the representative volume of the component.

3.1 Results by Varying Shot Velocity

Velocity	Shot Size	Shot Angle	Shot Distance	Residual stress	P_{set}
10	1	90	150	10.22	0.0008
15	1	90	150	11.33	0.0008
20	1	90	150	14.01	0.0009
25	1	90	150	17.14	0.0009
35	1	90	150	24.18	0.0014
45	1	90	150	28.13	0.0020

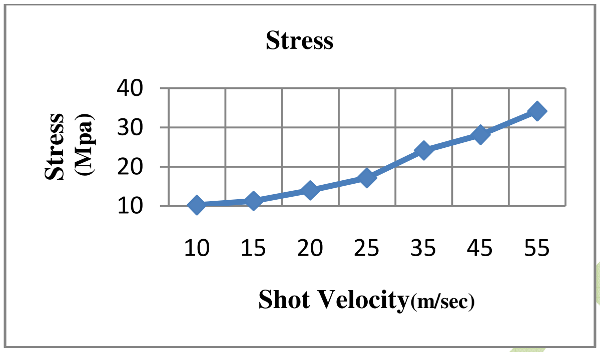


Fig. 3.1.1: Graph of Shot Velocity V^s Stress

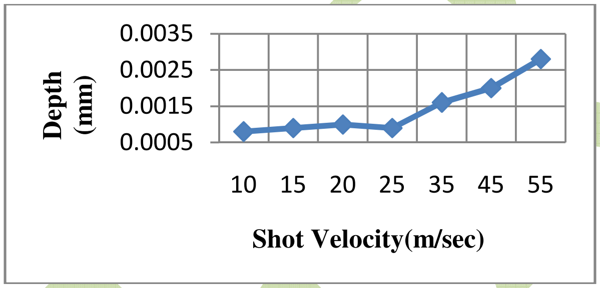


Fig. 3.1.2: Graph of Shot Velocity V^s Depth

3.2 Iteration by Varying Shot Angle

Velocity	Shot Size	Shot Angle	Shot Dist.	Residual stress	P_{set}
35	1	15	150	38.23	0.0015
35	1	25	150	33.12	0.0018
35	1	40	150	24.53	0.0005
35	1	55	150	38.28	0.0014
35	1	65	150	34.65	0.0009
35	1	80	150	10.33	0.0001

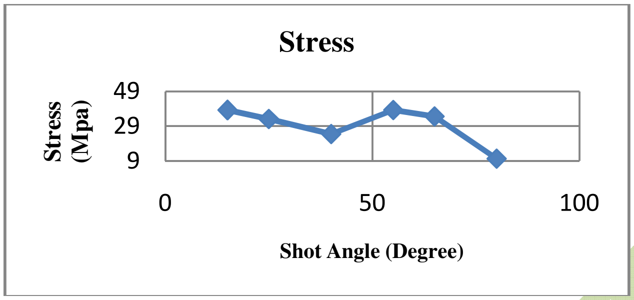


Fig 3.2.1: Graph of Shot Angle v^s Stress.

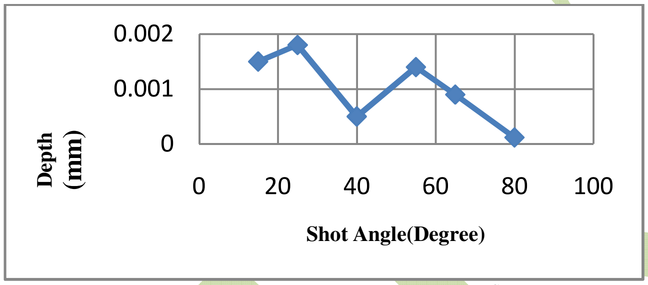


Fig 3.2.2: Graph of Shot Angle v^s Depth.

3.3 Iteration by Varying Shot Distance

Velocity	Shot Size	Shot Angle	Shot Dist.	Residual stress	P_{set}
35	1	15	80	10.15	0.0007
35	1	25	100	12.16	0.0008
35	1	40	115	14.13	0.001
35	1	55	120	15.10	0.0009
35	1	65	135	16.30	0.0009
35	1	80	170	18.10	0.0016
35	1	80	200	18.16	0.0017

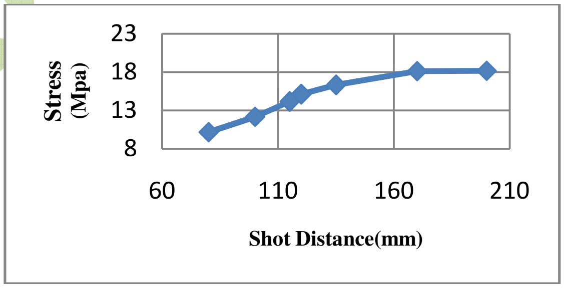


Fig.3.3.1: Graph of Shot Distance v^s Stress.

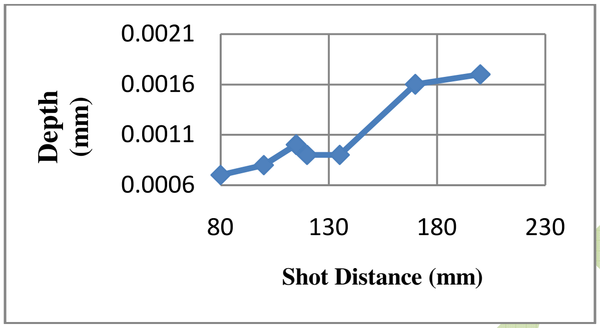


Fig.3.3.2: Graph of Shot Distance v^s Depth.

3.4 Iteration by Varying Shot Size

Velocity	Shot Size	Shot Angle	Shot Distance	Residual stress	P_{set}
35	0.85	90	150	14.13	0.001
35	0.65	90	150	19.20	0.0008

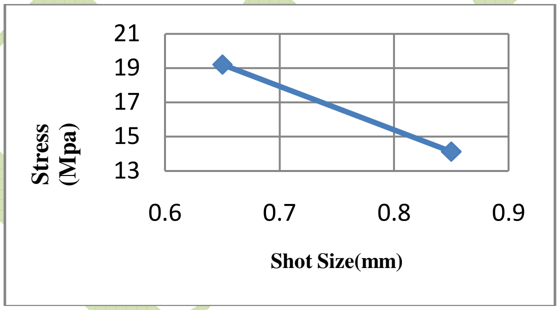


Fig.3.4.1: Graph of Shot Distance v^s Stress.

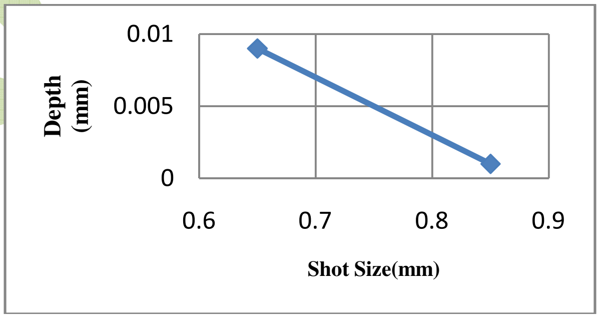


Fig.3.4.2: Graph of Shot Size v^s Depth.

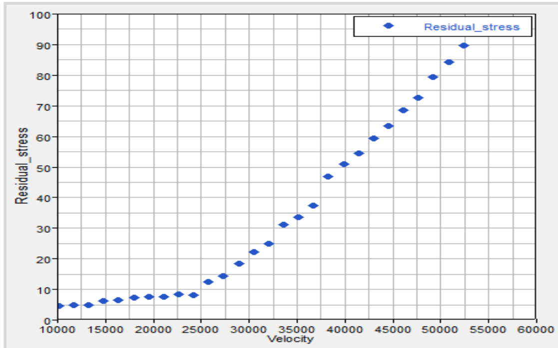


Fig.3.4.3: Graph of Velocity v^s Residual stress.

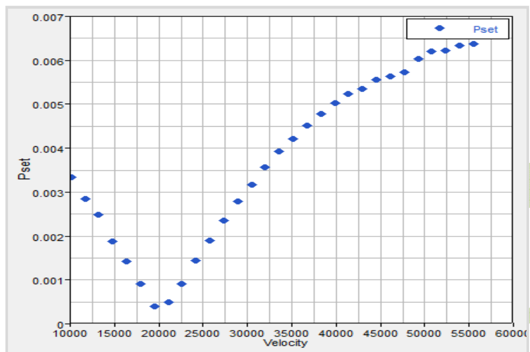


Fig.3.4.4: Graph of Velocity v^s Permanent set.

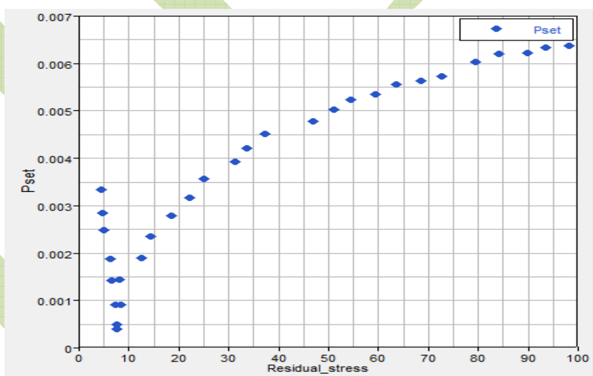


Fig.3.4.5: Graph of Residual Stress v^s P_{set}.

The Fig.3.4.3, Fig.3.4.4, Fig.3.4.5 shows first DoE results, the variation of residual stress & permanent set is observed at shot velocity 15 to 25 m/sec. So the second DOE will be carried out for various parameters like Shot velocity, Shot size, Shot angle & Shot distance.

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DESIGN OF EXPERIMENT

	Velocity	Size	Angle	Distance
Levels	15000	0.65	25	80
	15000	0.75	40	100
	15000	0.85	55	120
	20000	0.65	40	120
	20000	0.75	55	80
	20000	0.85	25	100
	25000	0.65	55	100
	25000	0.75	25	120
	25000	0.85	40	80

From the run summary the analysis result is getting. The results show that maximum residual stresses & minimum permanent set at particular parameter value. These results are given below:

Velocity	Angle	Size	Residual Stress	P_{set}
25.038	55	0.40	10.076	0.008862
25.036	25	0.40	10.079	0.008865
25.031	40	0.40	10.077	0.008860

The purpose of Shot Peening process is to enhance the Fatigue Life of Material. Experimentation is carried out on Centrifugal blast wheel Machine, after carrying out the experimentation following results are obtained. By Shot Peening the Residual stresses (compressive stresses) will be induced inside the material. The Fatigue Test is carried out before and after Shot Peening and the results shows that the fatigue life of material getting increased.

Parameters	Test Condition (Actual)	Permissible cond^{n}
Shot Size	0.50 mm	0.40 mm
Shot Velocity	38.46 m/sec	25.03 m/sec
Shot Angle	45	40
Shot Distance	2 m	2 m
Residual Stress	9.25 Mpa (avg)	10.07
P_{set}	0.015 (avg)	0.008

From the validation & analysis result the residual stress and permanent set are nearly equal.

CONCLUSION

The proposed method was used for enhancing the fatigue life of Aluminum 2024 (Al2024) material. For that purpose shot peening process used, the residual stress (compressive stress) form inside the material measured by Hole Drilling Strain Gauge method and fatigue life measured by three point bending test method. The conclusions are summarized as follows.

i) The Finite Element Model of the Target and Shot is created and analyzed for the residual stress and permanent set by using LS Dyna Software (as a solver). The results are compared with Experimental model analysis using centrifugal blast wheel machine for validation of model.
ii) The number of factors like Shot velocity, size, angle, distance affecting on process, so that to determine the relationships between the different factors affecting a process and the output of that process Minitab software is used for Design of Experiments (DoE).
iii) From FE analysis result, the residual stress is found to be 10.0770 Mpa and permanent set to be 0.00886 mm. The results of the Experimentation recorded for residual stress are 9.25 Mpa & Permanent set as 0.015 mm.

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